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A MEASUREMENT OF THE FINE STRUCTURE
OF THE THERMAL FLUX
IN SIMPLE-GEOMETRY ORGEL TYPE LATTICES

by

A. BOEUF and S. TASSAN

1963



ORGEL Program

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Neutron Physics

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SUMMARY

A measurement of the fine structure distribution of the thermal flux in simple-geometry natural uranium - heavy water - organic lattices has been performed by activation of dysprosium detectors. Two organic compounds, i.e. monoisopropyldiphenyl (Monsanto) and diphyl (Bayer), have been investigated. The results of the experiment have been compared with the values calculated by the AMOUYAL-BENOIST method.

INTRODUCTION

One parameter important to the neutron economy of natural uranium, heavy water moderated, organic cooled reactors (i.e. ORGEL type reactors) is the thermal disadvantage factor of the system fuel-organic coolant. Of greater interest to the physics of such reactors is the knowledge of the fine structure distribution of the thermal flux in the fuel element. The direct calculation of either quantity may present some difficulty, mainly due to the uncertainty in the nuclear constants of the organic compound.

In order to test the accuracy of calculated values with a set of experimental data and to provide parameters of direct application to reactor design, two fine structure measurements were planned, respectively on simple-geometry fuel elements and on ECO cluster elements (see ref. 1 for details on ECO fuel elements). The critical facility selected for the experiment was AQUILON II, a heavy water moderated assembly at CEN, SACLAY, made available through a contract with CEA.

In this report the experimental technique adopted for the first measurement is described and the results obtained are compared with the values calculated using a simple theoretical model.

EXPERIMENTAL TECHNIQUE

A. Fuel element design

The simple-geometry fuel element investigated consisted of a natural uranium rod, aluminum clad, contained in an aluminum tube filled with organic liquid. Its dimensions were :

diameter uranium	44 mm
length uranium	2000 mm (8 segments, 250 mm each)
inner diameter clad	45 mm
outer diameter clad	47 mm
pressure tube thickness	1.5 mm

Details of the fuel element design are shown in fig. 1. Two organic liquids were investigated, i.e. diphyl (26.5% $C_{12}H_{10}$ -73.5% $C_{12}H_{10}O$, a Bayer product) and monoisopropyldiphenyl ($C_{15}H_{16}$, a Monsanto product), the latter being the compound used in ECO. The thickness of the organic layer surrounding the rod was varied from 3 mm to 5 mm.

B. Thermal flux detectors

The spatial flux distribution in the fuel element was determined by activation of dysprosium detectors. Although the activation cross section of this element does not follow the $\frac{1}{v}$ law as it was originally believed, the required correction to the data can be performed using the measured Dy^{164} resonance parameters (2). On the other side Dy^{164} has the lowest epi-cadmium activation among the usual thermal flux detectors, which is a very convenient feature for fine structure type measurements.

The detectors used were disks of pure dysprosium metal, 2 mm in dia. and 5/100 mm thick, intercalibrated by irradiation (3). They were inserted in vertical slots, precision-machined in natural uranium cylinders and in plastic ring - supports, placed respectively between the segments of the fuel rod and in the organic liquid. The detectors in the uranium were sandwiched between two high purity aluminum disks, 0.03 mm thick and 2 mm in dia., to prevent their contamination by fission product capture.

Calculation of the shadow-effect among the foils, performed by methods which assumed perturbation sources of different geometries (4), indicated an effect smaller than 0.4% at spacings greater than 6 mm. This value was chosen as the minimum distance among adjacent foils, which were consequently arranged at two different levels in order to obtain a finer mesh flux distribution. The detector arrangement in the uranium and in the organic at both levels is shown in fig. 2. Foils placed at the same radial position were used to intercalibrate the induced activities; foils symmetrically placed allowed for a macroscopic flux correction to the fine structure in the case this would have been required.

C. Detector holders design

Preliminary calculations of the fine structure of the thermal flux in the elements under study put in evidence a high flux gradient across the organic layer, corresponding to a variation of about 1.5% in the flux for a 0.10 mm variation in the radial distance. It was thus evident that accurate results could be obtained only by resorting to a high-precision fabrication of the detector holding elements.

The problem was further complicated by the fact that very low tolerances could not be set for the dimensions of the fuel element, due to its considerable length. As shown in fig. 1, the standard fuel element exhibits a 0.5 mm clearance between the rod and the clad (ϕ^o fuel = 44.0 mm, ϕ^i clad = 45.0 mm). In order to eliminate the corresponding uncertainty in the radial position of the detectors placed in the uranium the diameter of the detector holder in the fuel was increased to 44.75 mm. The cladding tube of the fuel element where the detectors were to be placed was slightly modified to allow the insertion of the foil holding cylinders from both ends, and its inner diameter was rectified in order to guarantee a smooth motion of the oversized cylinders through it. Design details of this "measuring element" are shown in fig. 3.

The choice of the material for the holders of the detectors in the organic presented also some difficulty, since the two organic liquids selected are solvents for the plastics usually employed in this kind of measurements, i.e. plexiglas, expanded polystyrene, normal polystyrene, etc.. A serie of tests determined the choice of polyethylene.

Details of the detector holders are presented in figg. 4 to 7.

The width of the slots is 0.20 mm in the uranium and 0.10 mm in the plastic. Their radial distance from the center of the uranium cylinder and, respectively, from the inner surface of the plastic ring, is determined with a tolerance of 2/100 mm. The overall uncertainty in the radial position of the detectors in the fuel element is estimated to be less than 0.10 mm. As indicated later, the experimental procedure allowed to reduce considerably the effect that this uncertainty has on the data.

D. Epithermal correction factor

The small, but not negligible, epi-cadmium activation of the Dy detectors was corrected for by the cadmium difference technique. Two sets of Dy detectors, 4 mm in dia. and 5/100 mm thick, were used respectively in the organic and in the fuel, placed into holders identical to those previously described. Each set consisted of one bare foil and one cadmium covered foil, symmetrically placed with respect to the axis of the fuel element (fig. 8). The cadmium box had a thickness of 0.80 mm, corresponding to an effective cadmium cut-off energy of about 0.50 ev (5).

The radial position of the detectors for the cadmium difference measurement was the same as that of corresponding detectors for the fine structure measurement. This arrangement permitted the determination of the cadmium ratio relative to each experimental point, since the epicadmium flux is practically flat across the fuel element. Using the point-by-point value for the cadmium ratio so determined and the resonance parameters of Dy 164, the correction for the activation induced by the flux at energies between the joining point ($E = 5kT$) and the cadmium cut-off was computed (see appendix). The magnitude of the epithermal correction factor is indicated in tables 1 to 3.

E. Substitution pattern

Thirteen ORGEL type fuel elements (fig. 1) were substituted in the central zone of the AQUILON II reference lattice, in order to insure around the measuring element both a spectral energy distribution of the flux typical of the lattices studied and a reasonably smooth macroscopic flux distribution. The pattern of the substitution is indicated in fig. 9. The substituted lattice is not centered with respect to the reference lattice. An equivalent centered substitution pattern would have required a considerably larger number of rods and was considered unnecessary.

Requirements of the experimental program carried on with AQUILON II at the time of the measurement determined the available reference lattice.

Such a lattice consisted of an array of clusters of 7 Al-clad UO_2 rods, 22 mm in dia. and 2000 mm long, contained in an Al tube ($\phi_i = 106$ mm, $\phi_e = 108$ mm), filled with air; the spacing of the rods in the cluster and the pitch of the lattice were respectively 32 and 240 mm, center to center. More details of the AQUILON II facility may be found elsewhere (6, 7). Calculations (8) showed that the buckling of this reference lattice was of the same order of magnitude of those of the lattices analyzed, and that consequently the distortion in the macroscopic distribution of the thermal flux in the vicinity of the measuring rod, resulting from the substitution, would have not caused a serious difficulty in the interpretation of the results. The experimental results proved the correctness of this assumption.

F. Irradiation procedure

In order to limit the number of activations required for each measurement two sets of detectors for the fine structure, each consisting of 46 foils, and one set of 4 foils for the cadmium ratio, were placed in the measuring rod. The fine structure detectors were positioned in the zone of maximum flux (and minimum flux gradient), experimentally determined. Details of the detector arrangement in the measuring rod are given in fig. 10. Two irradiations were performed for each of the three cases investigated, i.e. :

<u>organic liquid</u>	<u>thickness organic layer</u>
monoisopropyldiphenyl	3 mm
"	5 mm
diphyl	5 mm

Measurements were carried out in the three directions shown in fig. 9.

Counting of the induced activity was carried out by a chain consisting of eight beta scintillation counters (9), equipped with an automatic system for registration of the counts and advancement of the detectors on the chain. The reduction of the data was performed by an IBM 7090, using a code which provided the usual corrections for background, dead time, efficiency and decay of the detector, and counter efficiency. Both operations were performed by CEA personnel.

RESULTS

A. Experimental values

The results of the measurements are presented, in different forms, in tables 1 to 3 and figures 11 to 13. The quoted errors are the mean square deviations of the mean of a set of 4 to 12 independent values. In these errors, as well as in those indicated in table 4, the contribution of a hypothetical systematic error is neglected.

Since each set of values was obtained from irradiations performed using different detector holders (both in the fuel and in the organic), detectors, and measuring rods, these deviations already contain the effect of the uncertainties in the values of detector efficiency, radial position of the detector, etc., all of random nature. The same procedure considerably reduced the chances for the presence of systematic errors. The error deriving from the uncertainty in the relative axial position of the detectors in the three media (uranium, organic and heavy water), which was of the order of 1-3 mm, was experimentally proved to be negligible.

The origin of the compounded errors quoted in tables 1 - 3 is believed to be mainly in the uncertainties relative to the detector efficiency (known to about 1%⁽¹⁾), and secondarily in those relative to the detector position in the counter (a variation of the distance detector-scintillation crystal of 1/10 mm produces a variation of 0.3% in the relative counting rate) and to the radial position of the detector in the fuel element.

Considering that this last effect alone can be of the order of 1.5% for a radial distance variation of 1/10 mm, the precision attained in this series of measurements is considered satisfactory.

⁽¹⁾ In fact the long use of the same batch of intercalibrated detectors, previous to the present measurement, with the associated wear and deformation, makes this value rather optimistic.

B. Calculated values

The experimental thermal flux-averages in the fuel and in the organic liquid have been compared with the values calculated by the model developed by A. AMOUYAL and P. BENOIST (10, 11).

The average value of the thermal flux in the two regions of interest was obtained by the Gauss formula applied to the 5th degree polynomial approximating the curve fitted through the experimental points. The error in the thermal disadvantage factors thus obtained is probably close to $\pm 0.5\%$.

The calculation was performed using the following values for the macroscopic scattering cross sections of the organic liquids : monoisopropyldiphenyl $2,486 \text{ cm}^{-1}$, diphyl $2,054 \text{ cm}^{-1}$. A corrective term for second collision capture was included in the treatment of the fuel region (10). Experimental and calculated values are compared in table 4, the agreement in all three cases considered is satisfactory.

A closer agreement could probably be obtained by a different choice of the zones into which the fuel element is subdivided by the AMOUYAL-BENOIST method and/or a slight modification of the neutron cross sections used for the calculation. In particular, the scattering cross section of the hydrogen atom in the organic molecule is certainly not known to better than $\pm 5\%$. The variation in the ratio "average thermal flux in organic/average thermal flux in the fuel" corresponding to a $\pm 5\%$ variation in the above parameter has been calculated to be of the order of $\pm 1-2\%$ for the cases considered.

In fact, such a closer agreement between experimental and calculated values would not have much physical significance, since :

- a) the accuracy generally expected from the AMOUYAL-BENOIST method is not better than $\pm 5\%$, even in simple geometry cases with well defined cross sections ;
- b) an empirical adjustment of the nuclear constants to optimize the agreement with the experimental data finds little justification when, as in the present case, only a limited number of data is available.

It is believed that the set of experimental data collected is considerably more accurate than the results of the AMOUYAL-BENOIST calculation, and could provide a test for elaborate fine structure calculation methods.

C. Thermal utilization factors

The thermal utilization factors of the fuel elements investigated have been calculated from the experimental values of the thermal flux averages in the uranium, organic and aluminum tubes.

Although the flux in the aluminum tubes was not measured, it was possible to estimate flux averages by extrapolating the experimental values obtained in the fuel, in the organic liquid and in the heavy water. These averages are compared with the values calculated by the AMOUYAL-BENOIST method in table 4. The agreement is deemed satisfactory, when considering :

- a) that the experimental value is only estimated, with an error which is believed to be of the order of 2-4% ;
- b) that the values of the flux in the aluminum are calculated with considerably less precision than in the fuel or organic, since the capture in the aluminum clad is only a minor fraction of the total capture in the fuel element; and especially so in the outer aluminum tube, which is at the boundary of the fuel element cell.

The experimental values of the thermal utilization factor are listed in the last column of table 4. The uncertainty in this parameter deriving from the statistical errors in the measured quantities (i.e. : neglecting any possible systematic error in the data and the error in the cross section values) is estimated to be of the order of $\pm 0.1\%$. The agreement with the calculated values of the thermal utilization factor (10,11), also listed in table 4, is good.

The implications of the measured fine structure distribution of the thermal flux and thermal utilization factors of the fuel element on the criticality of the lattices investigated, as well as of similar ORGEL type lattices, is beyond the scope of the present paper.

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APPENDIX - EPITHERMAL CORRECTION FACTOR

The correction for the epithermal component of the dysprosium induced activity has been performed by the cadmium difference technique. The effect of the non - $\frac{1}{v}$ behavior of the Dy^{164} cross section on such correction deserves some consideration.

For this purpose the energy spectrum of the neutron flux is adequately represented, both in the organic layer and in the fuel, by the Westcott model, i.e. a Maxwellian, followed by a $\frac{1}{E}$ distribution at energies above the joining point :

$$\phi(E) = A M(E) \quad E < E_j \quad (E_j = 5kT)$$

$$\phi(E) = \frac{B}{E} \quad E > E_j$$

Let :

$$A(T) = \text{Dy activation induced by neutrons of all energies :}$$

$$A(th) = \int_0^{E_j} A M(E) \sigma^{Dy^{164}}(E) dE = \text{Dy activation induced by neutrons at energies below } E_j \text{ per } Dy^{164} \text{ atom;}$$

$$A(E_j - E_{Cd}) = \int_{E_j}^{E_{Cd}} \frac{B}{E} \sigma^{Dy^{164}}(E) dE = \text{Dy activation induced by neutrons at energies from } E_j \text{ to } E_{Cd} \text{ per } Dy^{164} \text{ atom;}$$

$$A(E_{Cd} - \infty) = \int_{E_{Cd}}^{\infty} \frac{B}{E} \sigma^{Dy^{164}}(E) dE = \text{Dy activation induced by neutrons at energies above } E_{Cd} \text{ per } Dy^{164} \text{ atom.}$$

E_{Cd} being the energy of the effective cadmium cut-off. Then :

$$A(T) = A(th) + A(E_j - E_{Cd}) + A(E_{Cd} - \infty) \quad (1)$$

and :

$$C.R. = A(T) / (E_{Cd} - \infty) \quad (2)$$

From the above equations :

$$A(th) = A(T) \left\{ 1 - \frac{1}{C.R.} \left[1 + \frac{A(E_j - E_{Cd})}{A(E_{Cd} - \infty)} \right] \right\} \quad (3)$$

The braketed term being the epithermal correction factor.

The variation of the ratio $A(E_j - E_{Cd})/A(E_{Cd} - \infty)$ for Dy^{164} as a function of the effective cadmium cut-off has been calculated from the resonance parameters of this isotope and is shown in the following table .

E_{Cd}	$\int_{E_j}^{E_{Cd}} \sigma^{Dy 164}(E) \frac{dE}{E}$	$\int_{E_{Cd}}^{\infty} \sigma^{Dy 164}(E) \frac{dE}{E}$	$\frac{A(E_j - E_{Cd})}{A(E_{Cd} - \infty)}$	$\frac{A(E_j - E_{Cd})}{A(E_{Cd} - \infty)}$
(ev)	(barns)	(barns)	Dy 164	$\frac{1}{v}$ detector
0.40	824	388	2.124	0.789
0.42	845	371	2.278	0.833
0.44	864	351	2.461	0.876
0.46	882	333	2.649	0.918
0.48	898	317	2.833	0.960
0.50	913.5	302	3.025	1.000

The last column lists the values of same ratio for an ideal $\frac{1}{v}$ detector.

From the above table and eq. 3 results that the magnitude of the epithermal correction factor to the total induced activity of dysprosium is strongly dependent on the value of the effective cadmium cut-off, which in turn is a quantity often difficult to determine with high accuracy. Such a dependence is less strong for an ideal $\frac{1}{v}$ detector. Finally, it is evident that the error introduced in the epithermal correction factor by treating Dy as a $\frac{1}{v}$ detector may be appreciable.

The effect of the flux hardening in the fuel rod on the measured Dy¹⁶⁴ activities deserves some comment. The flux hardening in the uranium may produce an appreciable increase of the value of the Maxwellian temperature in the inner fuel region, with respect to that in the outer fuel region and in the organic layer. Such an increase would have an effect on the activity induced in the detector, if the Westcott g factor for Dy¹⁶⁴ would vary with the Maxwellian temperature. Such a variation has been calculated to be less than 0.3% for a temperature increase from 300°K to 400°K, i.e. negligible for the expected values of the flux hardening. An additional consequence of the flux hardening in the fuel is the shift of the "joining point" energy ($E_j = 5kT$), which may cause a significant variation in the ratio $A(E_j - E_{Cd})/A(E_{Cd} - \infty)$, that is in the epithermal correction factor. However, also the effect of the expected shift in E_j on the epithermal correction factor for Dy¹⁶⁴ is negligible.

In the present experiment the thickness of the cadmium box used for the cadmium difference measurement was 0.80 mm, corresponding to an effective cut-off of 0.49 to 0.51 ev, according to the chosen calculation model. For the cases considered this value is practically independent of the spectral composition of the flux distribution as well as of the exact value of the Maxwellian temperature. The corresponding uncertainty in the values for the epithermal correction factor is estimated to be in any case less than $\pm 0.15\%$.

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Medium	Natural uranium							Organic liquid			D ₂ O
Radial position (mm)	0	6	10	14	18	20	21	24	24.9	25.8	28.1
Total flux normalized to unity at position 0	1.000	1.048 + 0.004	1.134 + 0.006	1.288 + 0.003	1.506 + 0.004	1.652 + 0.018	1.746 + 0.014	2.211 + 0.007	2.616 + 0.010	2.869 + 0.008	3.267 + 0.014
Cadmium-ratio of dysprosium	91	95	102	117	137	149	158	198	235	257	293
				+ 5%					+ 5%		+ 5%
Epithermal correction factor	0.956	0.958	0.961	0.966	0.971	0.973	0.974	0.980	0.983	0.984	0.986
Thermal flux normalized to unity at position 0	1.000	1.050 + 0.006	1.140 + 0.008	1.302 + 0.005	1.530 + 0.007	1.681 + 0.021	1.779 + 0.018	2.267 + 0.011	2.690 + 0.015	2.953 + 0.014	3.370 + 0.020

TABLE 1 - RESULTS

Fine structure of the thermal flux

Organic liquid : Monoisopropyldiphenyl

Thickness of organic layer : 3 mm.

Medium	Natural uranium							Organic liquid					D ₂ O
Radial position (mm)	0	6	10	14	18	20	21	24	24.9	25.9	26.9	27.6	30.1
Total flux normalized to unity at position 0	1.000	1.046 + 0.002	1.123 + 0.005	1.259 + 0.006	1.489 + 0.001	1.608 + 0.032	1.720 + 0.012	2.141 + 0.016	2.471 + 0.011	2.804 + 0.026	3.126 + 0.015	3.400 + 0.028	3.647 + 0.022
Cadmium ratio of dysprosium	87	91	98	110	130	140	150	187	216	245	273	297	319
	± 5%							± 5%					± 5%
Epithermal correction factor	0.954	0.956	0.958	0.963	0.969	0.971	0.973	0.978	0.981	0.983	0.985	0.986	0.987
Thermal flux normalized to unity at position 0	1.000	1.048	1.127	1.271	1.512	1.637	1.754	2.195	2.541	2.889	3.227	3.514	3.773

TABLE 2 - RESULTS

Organic liquid : Monoisopropyldiphenyl

Thickness of organic layer : 5 mm.

Medium	Natural uranium							Organic liquid					D ₂ O
Radial position (mm)	0	6	10	14	18	20	21	24	24.9	25.9	26.9	27.6	30.1
Total flux normalized to unity at position 0	1.000	1.046 ± 0.002	1.120 ± 0.008	1.261 ± 0.009	1.487 ± 0.005	1.599 ± 0.022	1.704 ± 0.013	2.107 ± 0.014	2.405 ± 0.004	2.750 ± 0.021	3.055 ± 0.019	3.286 ± 0.016	3.539 ± 0.022
Cadmium ratio of dysprosium	79	83	89	100	118	127	135	167	191	218	242	260	281
	$\pm 5\%$							$\pm 5\%$					$\pm 5\%$
Epithermal correction factor	0.950	0.951	0.954	0.960	0.966	0.968	0.970	0.976	0.979	0.981	0.983	0.985	0.986
Thermal flux normalized to unity at position 0	1.000	1.047	1.124	1.274	1.512	1.629	1.740	2.164	2.478	2.840	3.161	3.407	3.673

TABLE 3 - RESULTS

Organic liquid : Diphyl

Thickness of organic liquid : 5 mm.

Organic liquid	Thickness (mm)	$\phi_{\text{ORG}} / \phi_{\text{U}}$		$\phi'_{\text{AL}} / \phi_{\text{U}}$		$\phi''_{\text{AL}} / \phi_{\text{U}}$		Thermal utilization factor	
		Experimental	Calculated (1)	Experimental	Calculated (1)	Experimental	Calculated (1)	Experimental (2)	Calculated (1)
Monoisopropyldiphenyl	3	1.910 ± 0.01	1.907	1.470	1.509	2.339	2.256	0.9568 ± 0.001	0.9572
Monoisopropyldiphenyl	5	2.099 ± 0.01	2.018	1.450	1.500	2.693	2.440	0.9334 ± 0.001	0.9364
Diphyl	5	2.069 ± 0.01	1.997	1.444	1.500	2.626	2.403	0.9425 ± 0.001	0.9448

ϕ_{U} = average thermal flux in the fuel

ϕ'_{AL} = " " " aluminum clad

ϕ''_{AL} = " " " aluminum pressure tube (outer clad)

ϕ_{ORG} = " " " organic liquid

(1) = the calculation was performed by the Amouyal-Benoist method (13, 14)

(2) = the quoted error is that deriving from the uncertainties in the measured quantities. The contribution of the uncertainty in the cross section values is neglected.

TABLE 4 - RESULTS

Disadvantage factors and thermal utilization factors

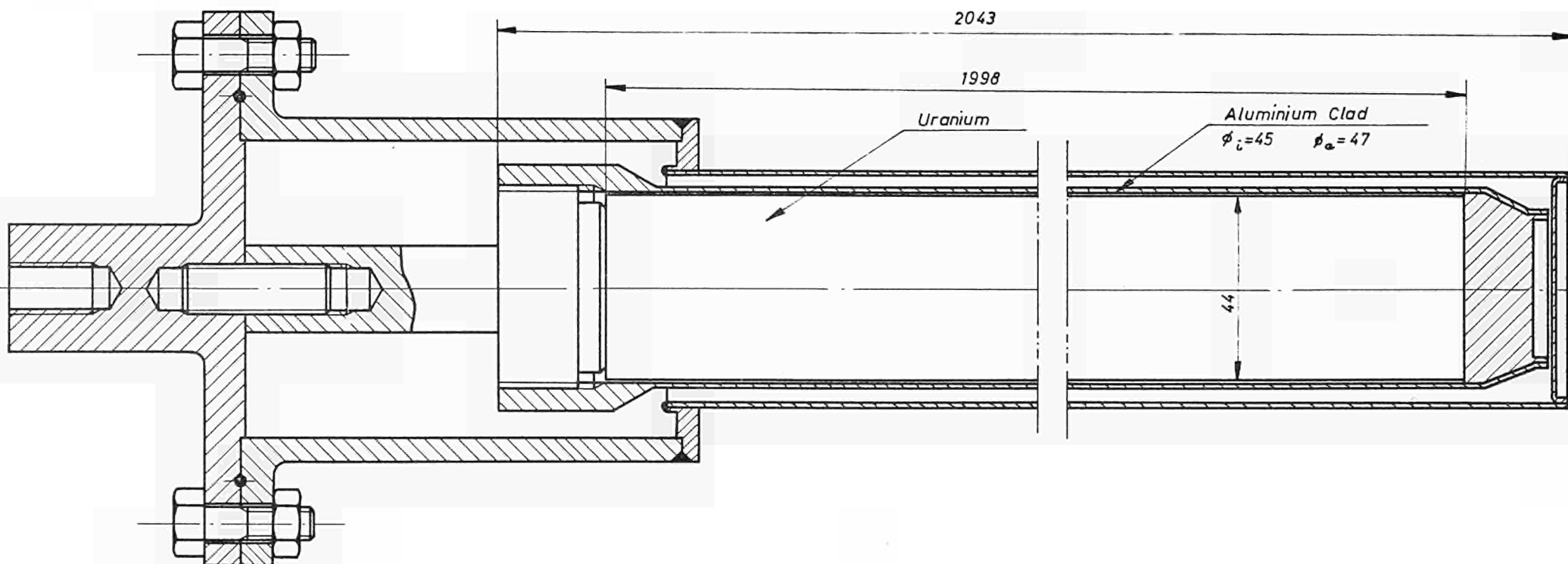
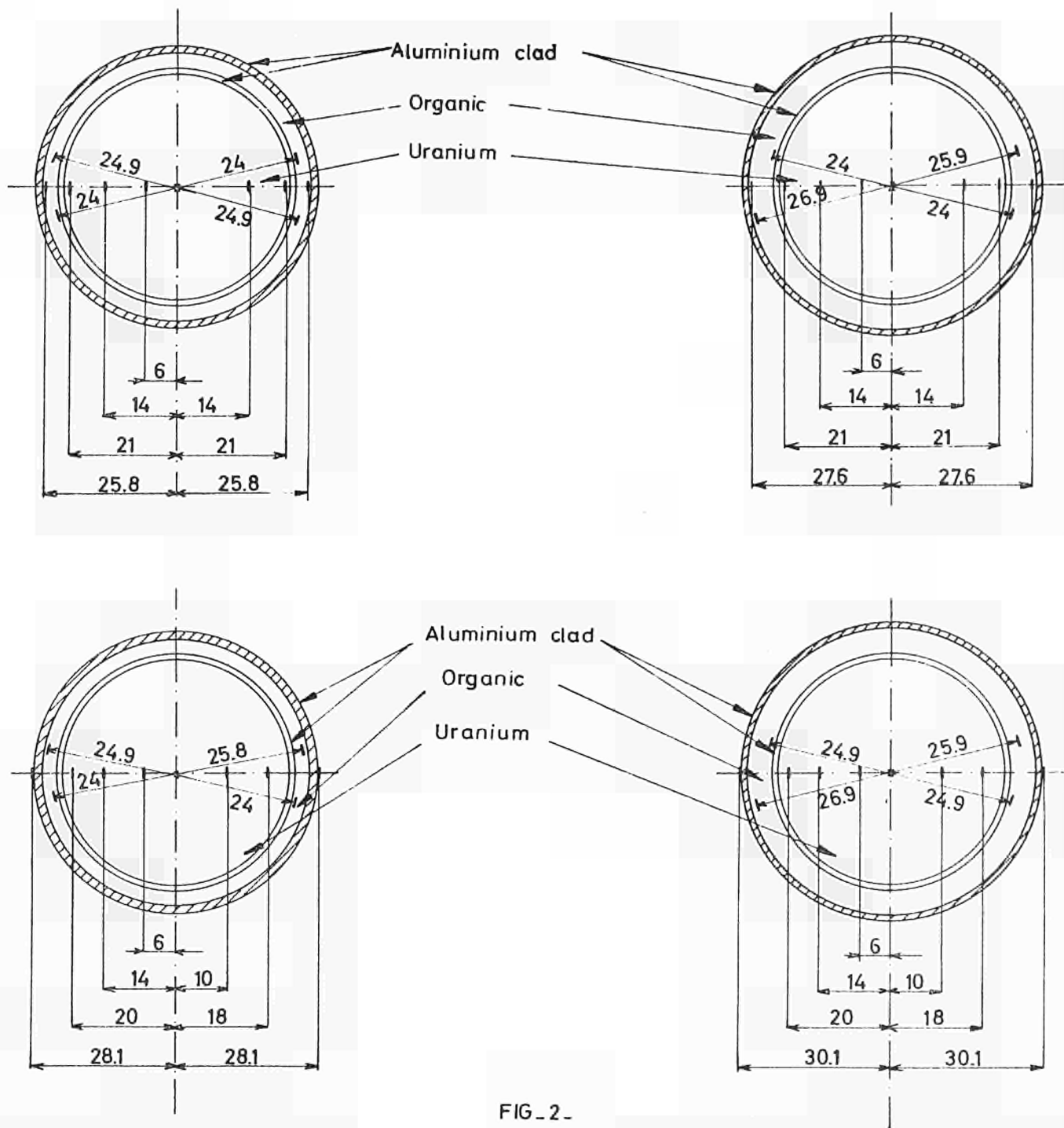


FIG.1_ Standard fuel element.



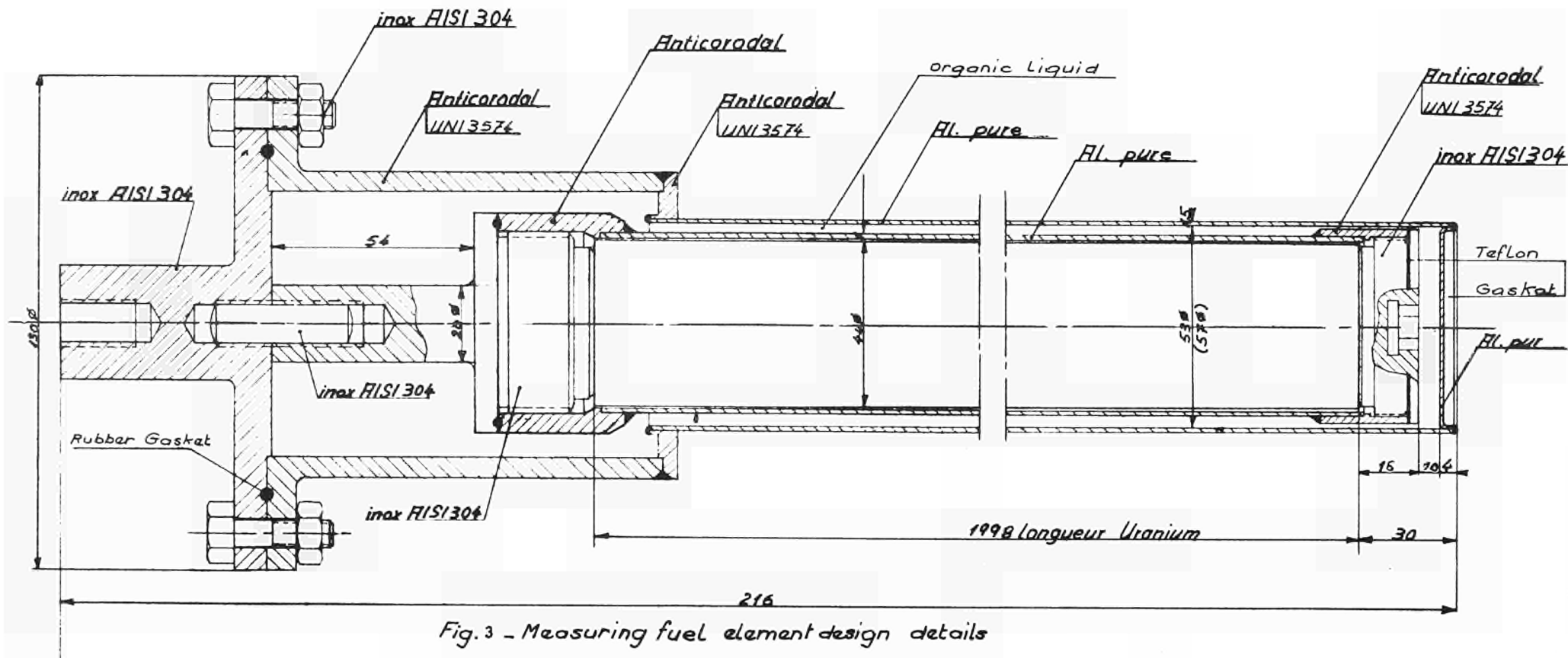
FIG_2_

A_Detector arrangement for the fine
Structure measurement.

Thickness of organic layer : 3 m m .

B_Detector arrangement for the fine
structure measurement

Thickness of organic layer : 5 mm.



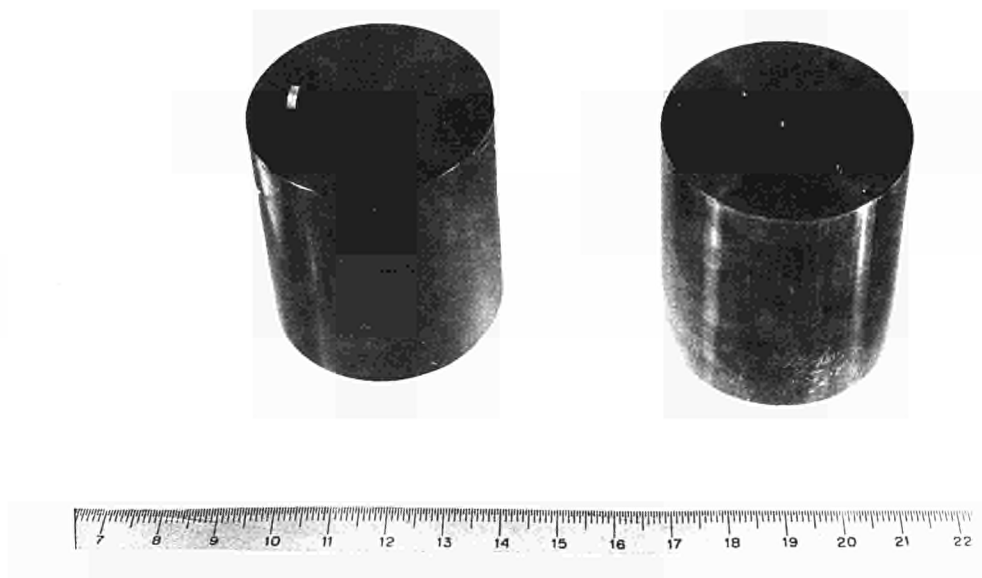


Fig. 4 Detector holders in the fuel

(Some detectors and the cadmium boxes are shown partially extracted)



Fig. 5 Detector holders in the organic
(Some detectors and the cadmium boxes are shown
partially extracted)

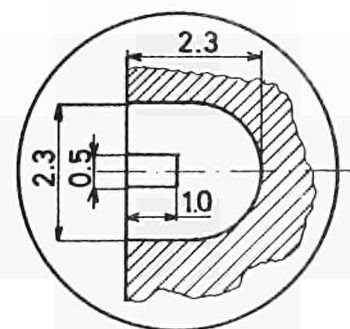
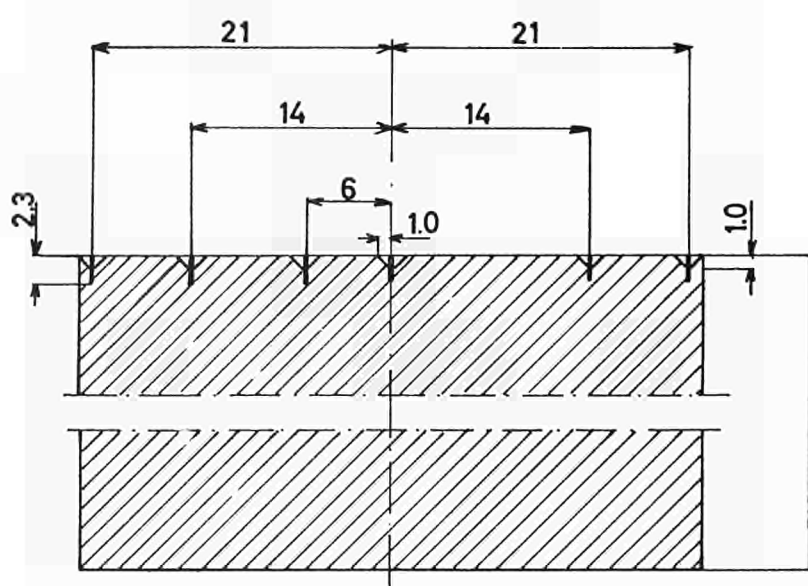
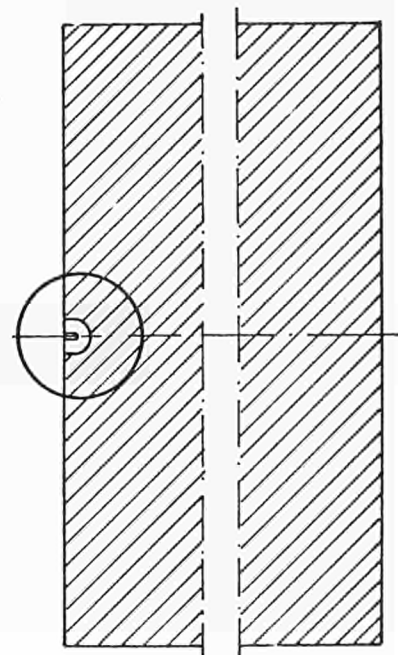
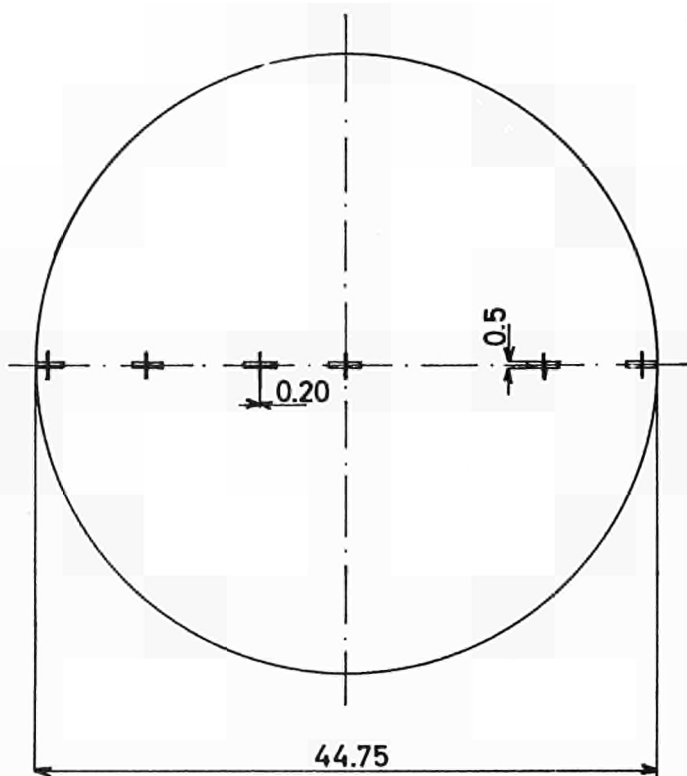
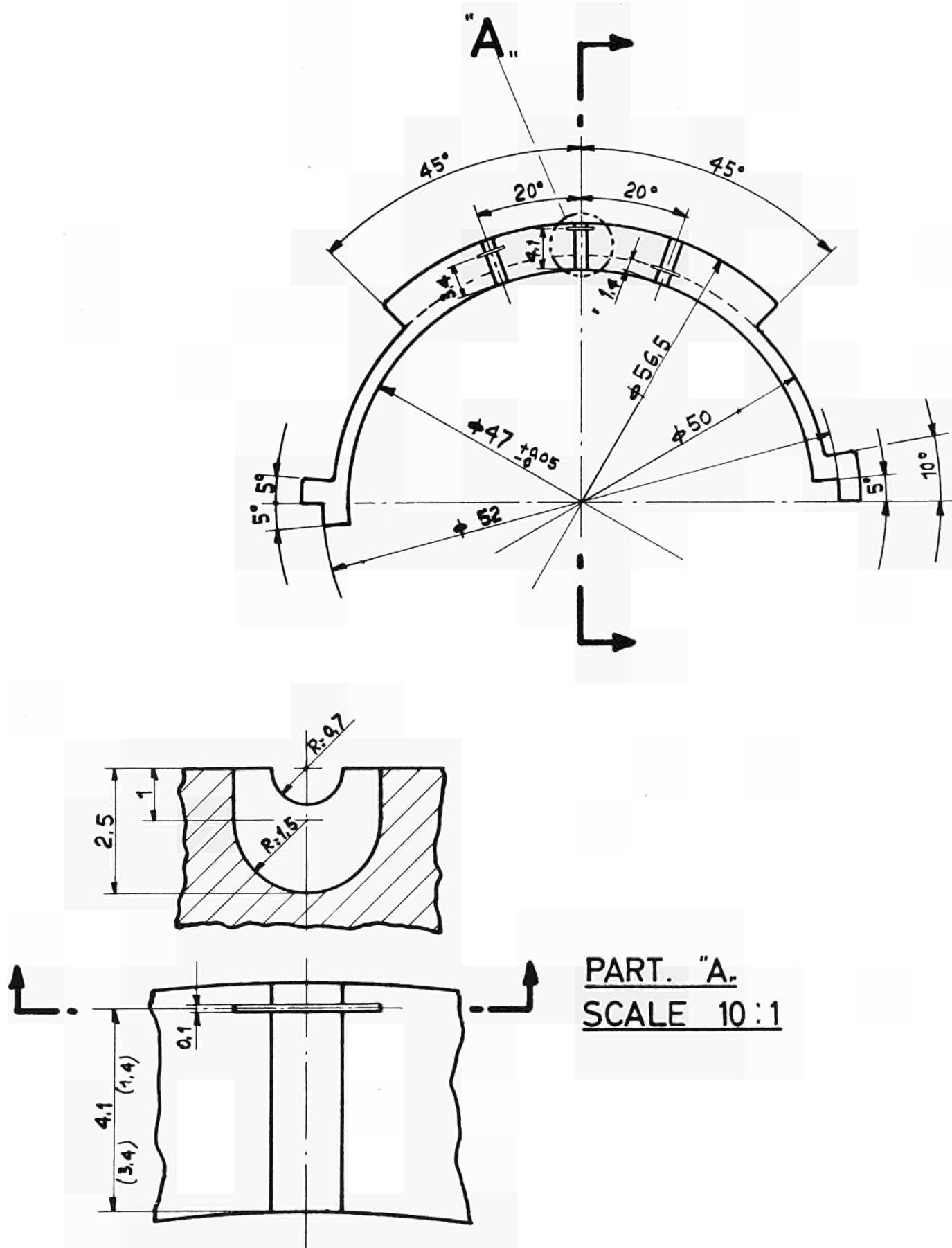
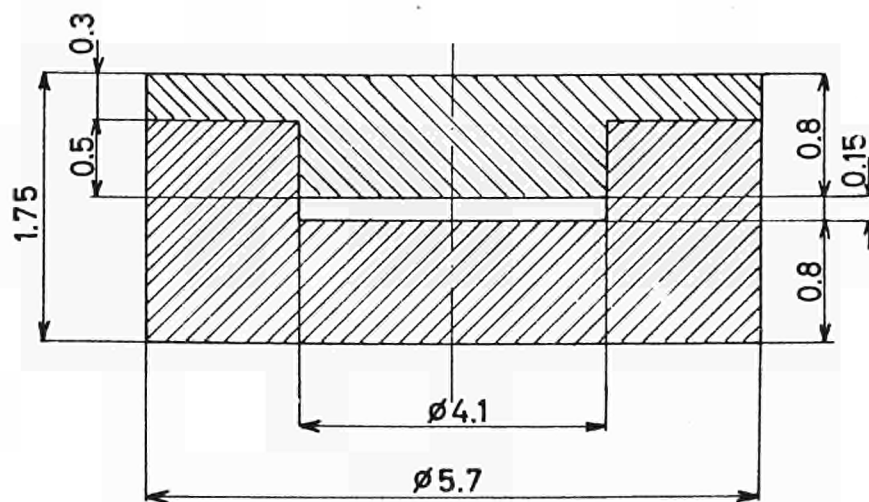
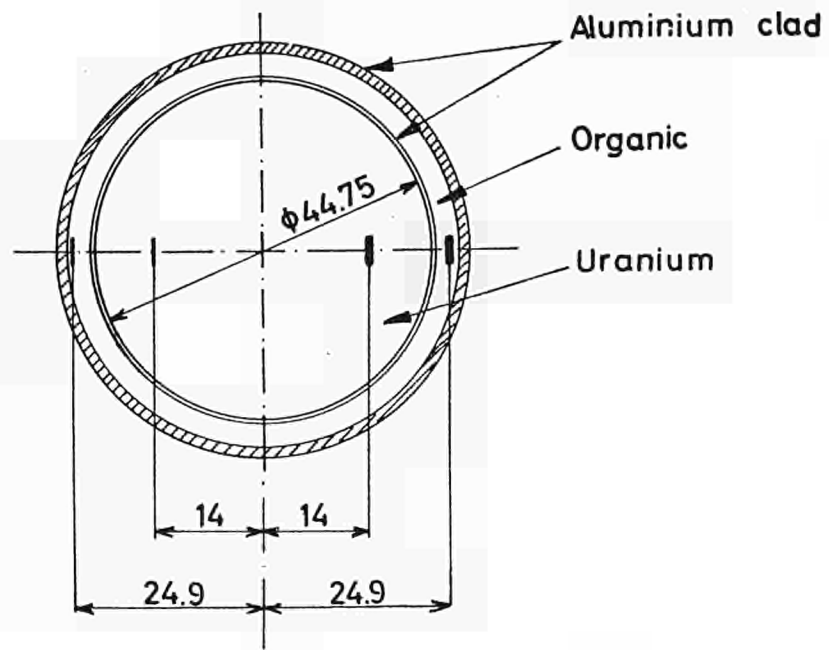


FIG-6 _Design details of the detector holder in the fuel



FIG_7_Design details of the detector holder in the organic



I - Bare detector

II - Cadmium-clad detector

FIG_8 _ Detector arrangement for the cadmium ratio measurement

(thickness of the organic layer :3mm) and details of the cadmium box .

Standard U fuel segments
(H= 50 mm, \varnothing =44.0 mm.)
(H=250 mm, \varnothing =44.0 mm.)

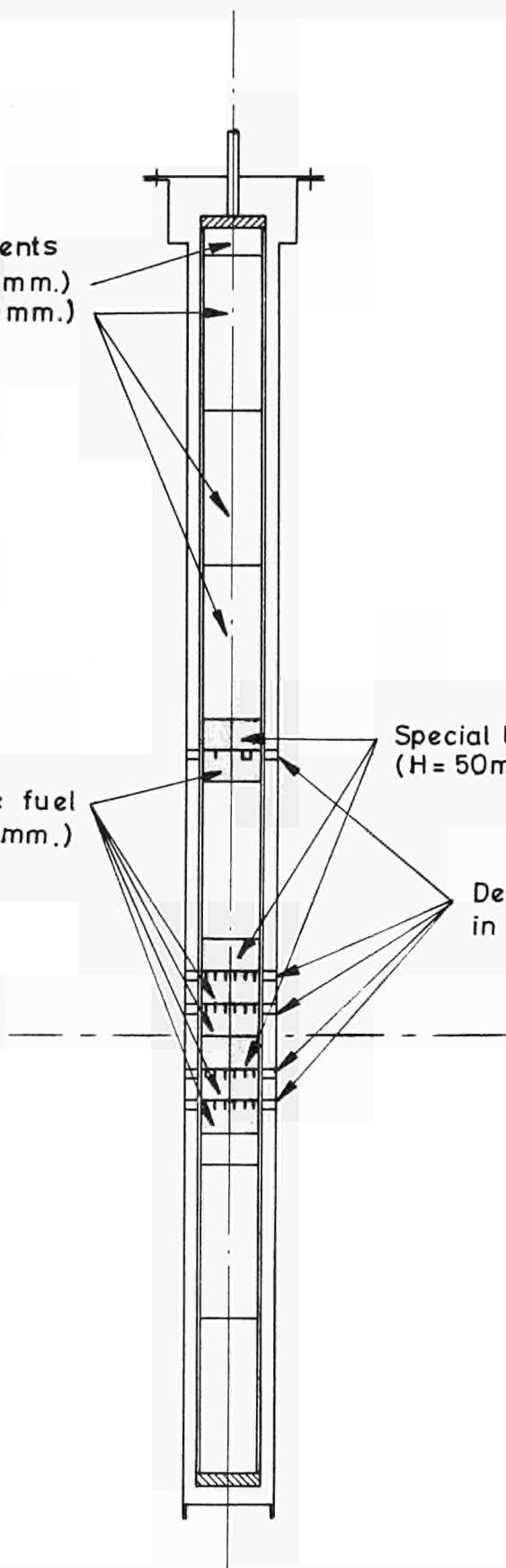
Detector holders in the fuel
(H= 50mm, \varnothing =44.75mm.)

Special U fuel segments
(H= 50mm, \varnothing = 44.75 mm.)

Detector holders in the organic

Maximum flux position

FIG_10_ Detector arrangement in the measuring rod
(not in scale .)



35

- Fig. 11 - Fine structure of the fuel
in the fuel element investigated

- Organic liquid: MIPD

- thickness of organic layer: 3mm

30

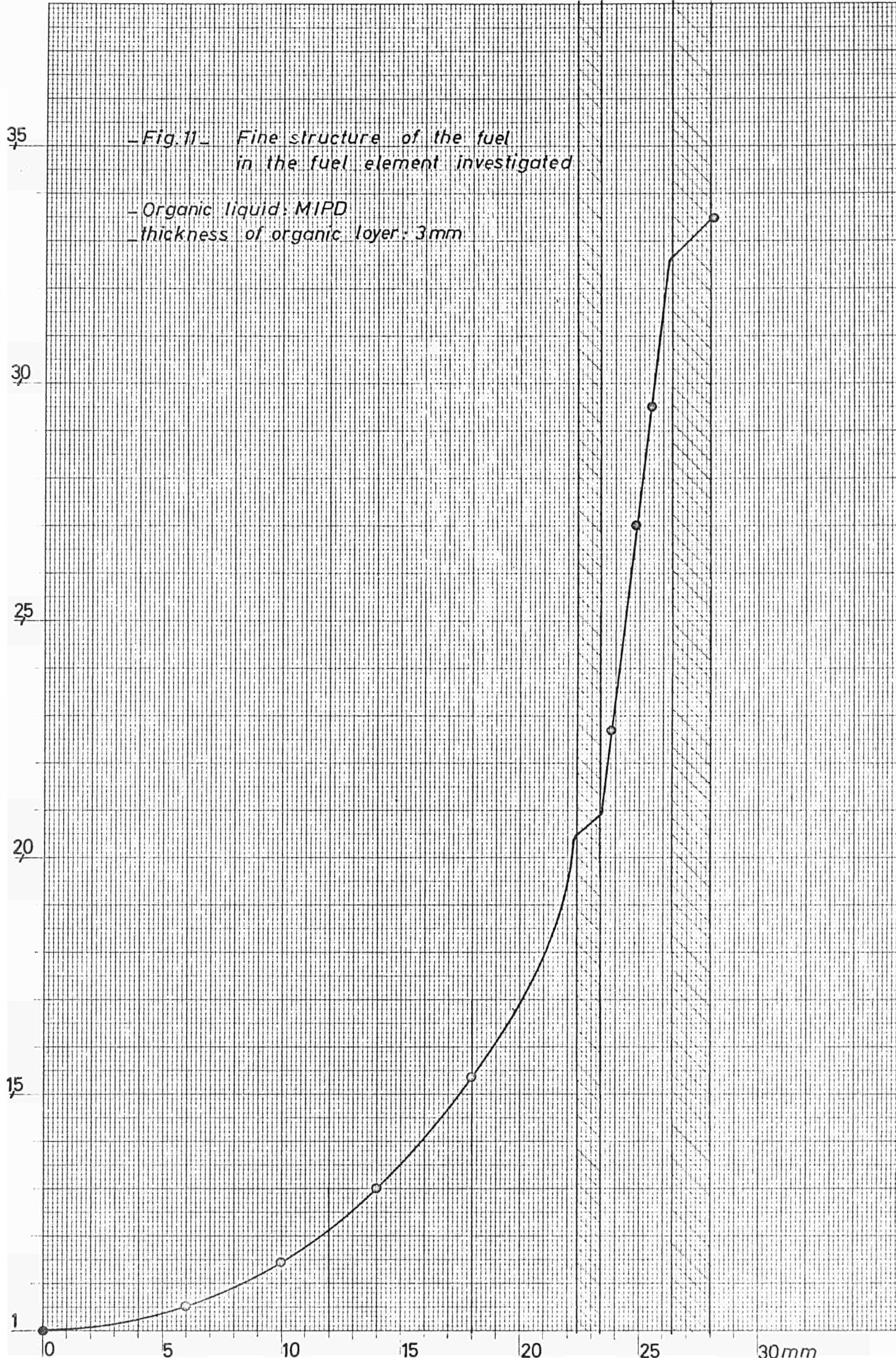
25

20

15

1

0 5 10 15 20 25 30mm



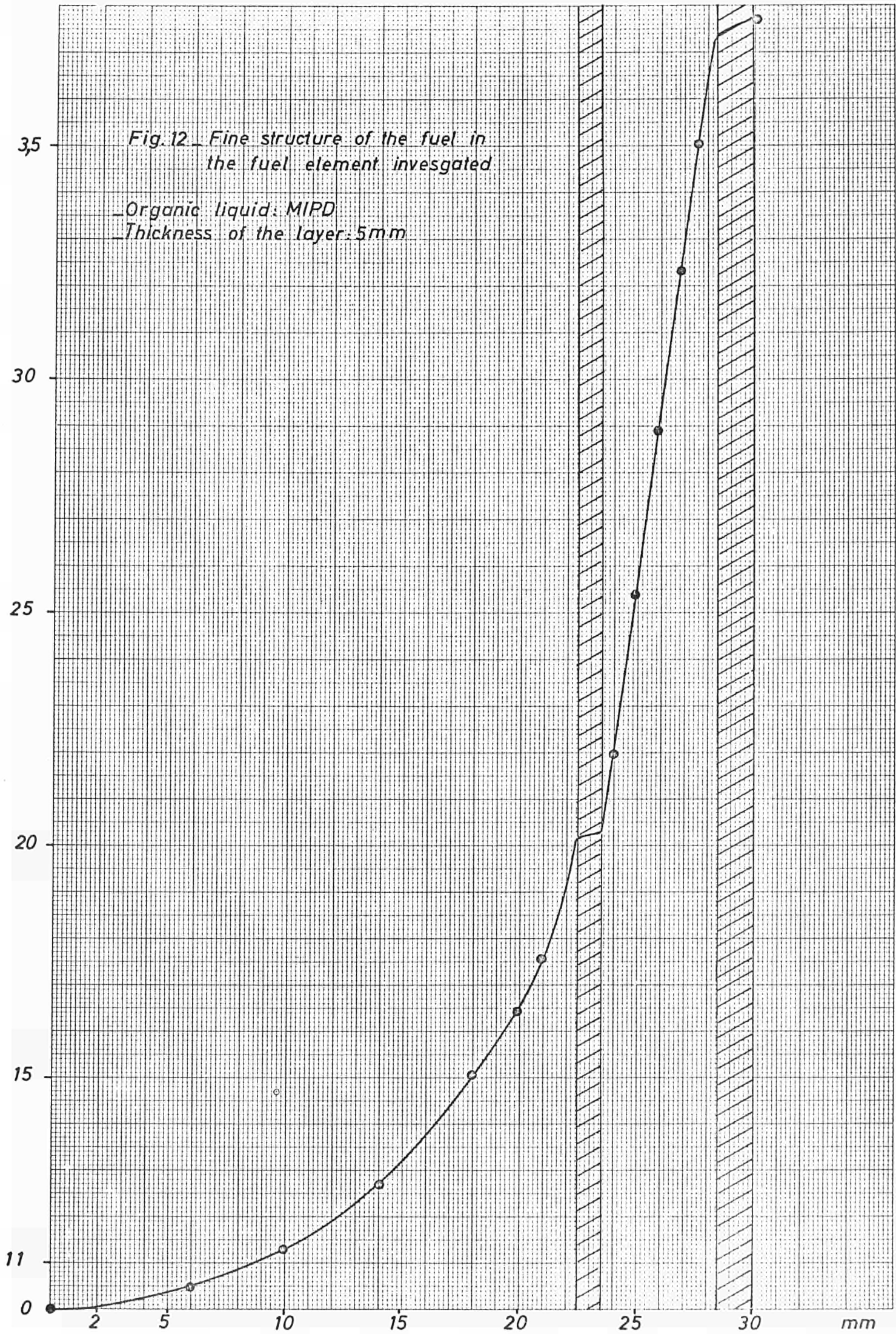
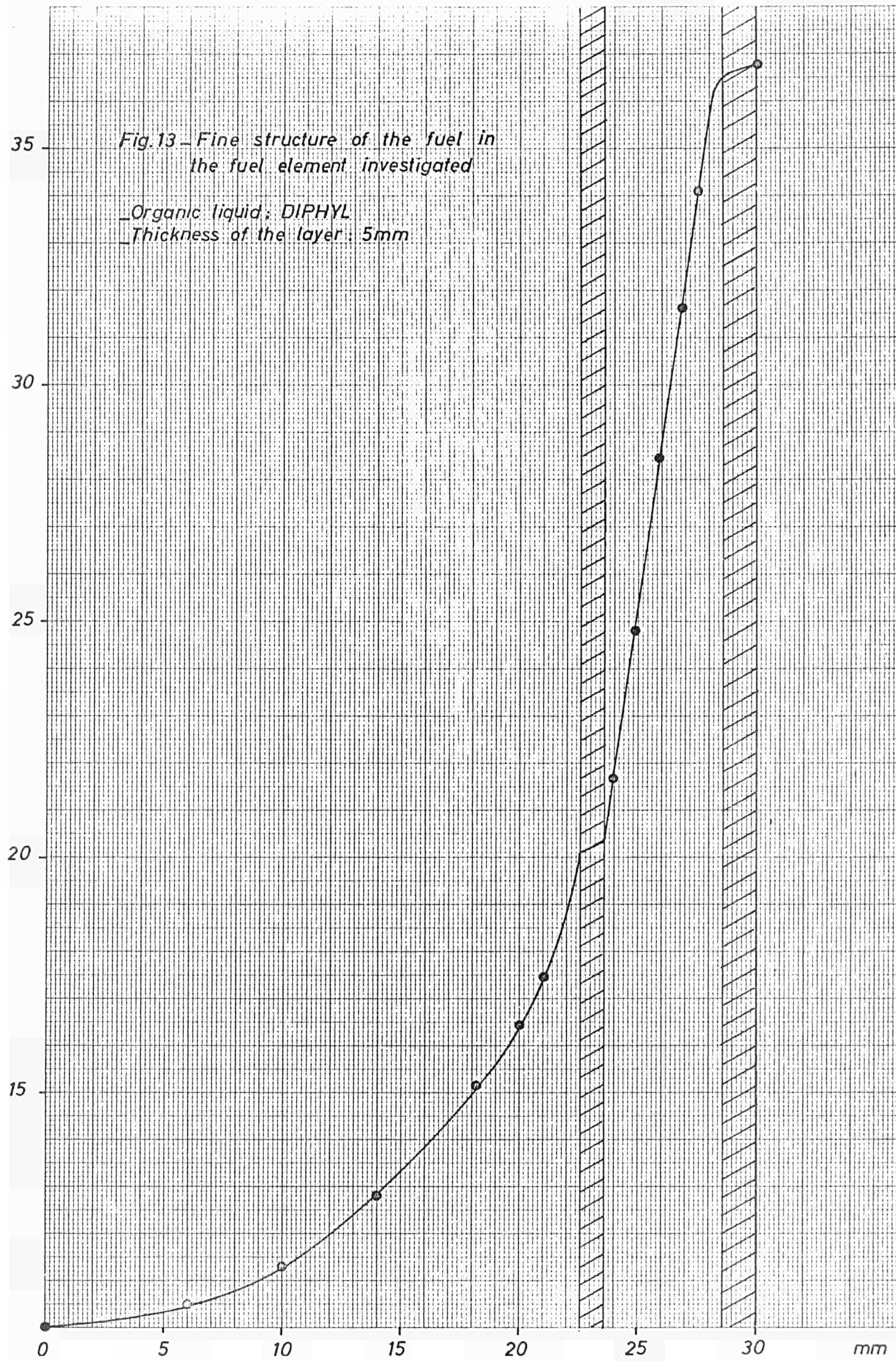


Fig.13 - Fine structure of the fuel in the fuel element investigated

Organic liquid; DIPHYL

Thickness of the layer: 5mm



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